Axsys Technologies Optical Systems
Cullman, AL

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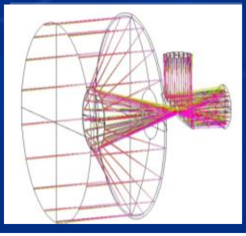




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Introduction

Design and Manufacturing considerations for 0.50 -1.5 meter beryllium telescopes for current and future space missions

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Abstract

Recently there has been renewed interest in several beryllium telescopes ranging in aperture from 0.50-1.5 meter in aperture for a range of NASA GSFC space missions.

The central design feature for each mission currently under consideration is an axially symmetric all beryllium two mirror telescope.

Abstract

Diamond point turning, coordinate measurement machine profilometry, computerized grinding and polishing, brazing of complex structures, very thin electroless nickel plating, and other advanced manufacturing technologies are essential to successful visible–NIR optical performance.

Current manufacturing efforts on a 1.0 meter beryllium telescope is profiled to illuminate the confluence of applicable design and manufacturing technologies.

Discussion

The following design and manufacturing technologies are pivotal to low cost high performing systems of this nature:

- Generalized design
- Beryllium grade
- Progressive machining, heat treat, thermal cycling
- Beryllium Brazing:
- Electroless Nickel Plating
- Diamond machining
- Computerized loose abrasive grinding and polishing
- Aspheric null testing technologies:
- Optical coating:

Generalized design

Legacy design form modified for scale, F/#, and instrument interface. All beryllium construction.

Cassegrain or Ritchey-Chretian optical design.

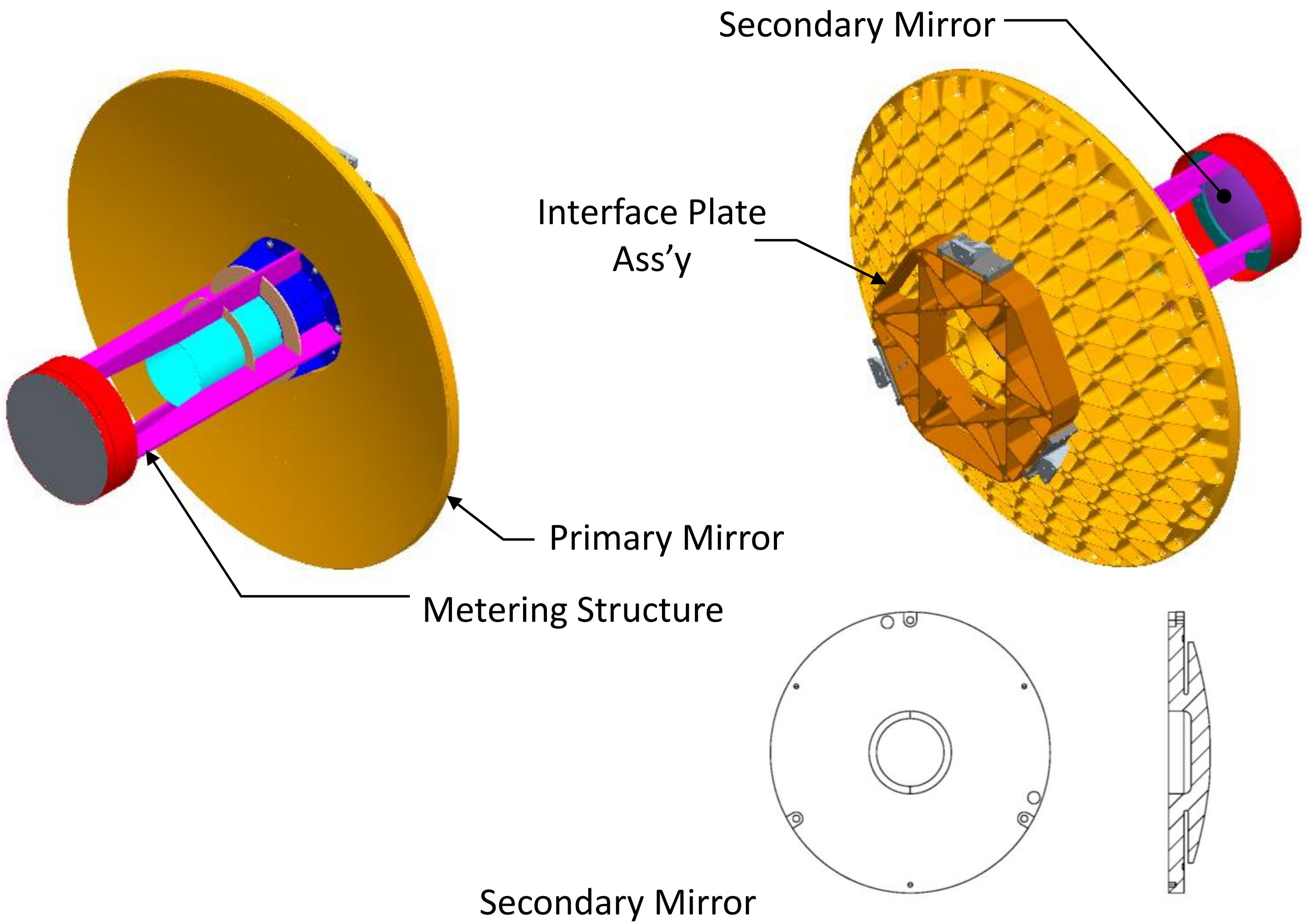
Brazed or machined M1-M2 center metering structure.

Light weight machined primary mirror.

Secondary mirror with integrally machined, strain relieved mounting flange.

Mirrors are thin nickel plated, diamond point turned and post polished for figure and finish in the presence of interferometric null tests.

Generalized design



Beryllium Grade Selection

Several grades of beryllium are available for consideration for telescopes of this nature.

Since it has been decided that the mirrors will be electroless nickel plated based on legacy, premium grades of beryllium suited for optical polishing such as O-30H or I-70H are not required. These grades also tend to have lower micro-yield due to lower beryllium oxide content.

Structural grades such as S-200F and S-200FH are practical for many beryllium telescope programs.

Materion I220H is selected by NASA based on heritage, high micro-yield, and isotropic expansion and contraction over temperature.

“H” designates hot isostatically pressed (HIP)
“F” designates vacuum hot pressed

General Beryllium Processing

Progressive machining, heat treating, thermal cycling, acid etching, interim Zyglo inspection, etc are critical to successful beryllium processing.

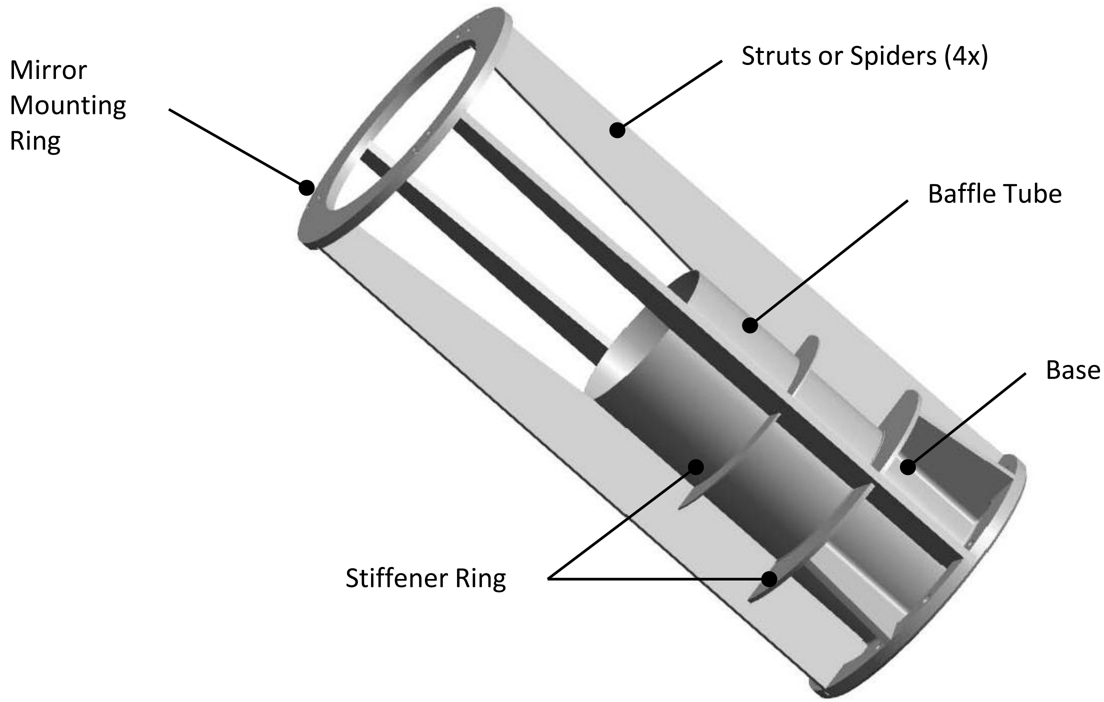
Beryllium mirrors require interations of thermal cycling and re-mounting during optical fabrication to verify dimensional stability and to verify repeatability of mounted interfaces.

Beryllium Brazing

Beryllium brazing is an effective technology to reduce cost and risk in the manufacture of large, complex beryllium structures.

On past NASA programs, many M1-M2 metering structures have been brazed construction

Beryllium Brazing (GLAS and others)



Beryllium Brazing

Brazing enables beryllium material savings and potential for structurally efficient design forms that cannot be machined such as semi-closed cell construction.

Brazing also enables parallel processing of much smaller components and de-brazing is feasible if repairs are required thus reducing risk compared to large hog out.

Recent cost analysis for 1.0 meter metering structure:

Hogged out from solid block of I-220H: $500,000.

Brazed from multiple machined I-220H pieces: $325,000.

Beryllium Brazing

A properly prepared braze joint has nearly negligible thickness.

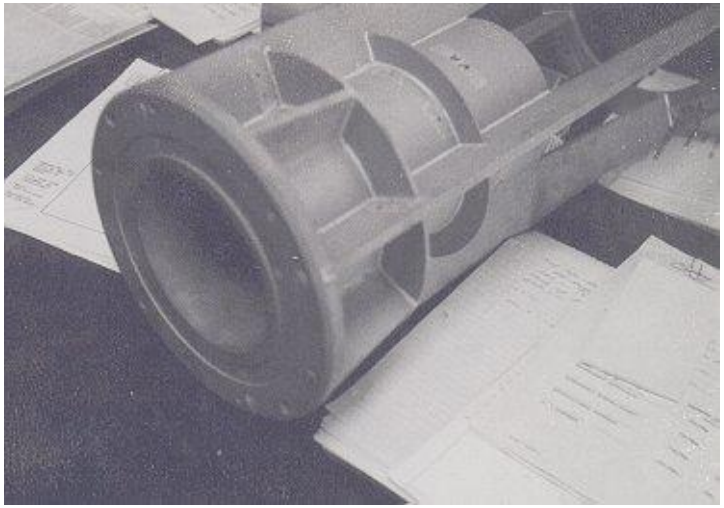
Very little mechanical distortion occurs during brazing due to low melting temperature of aluminum braze alloy compared to beryllium

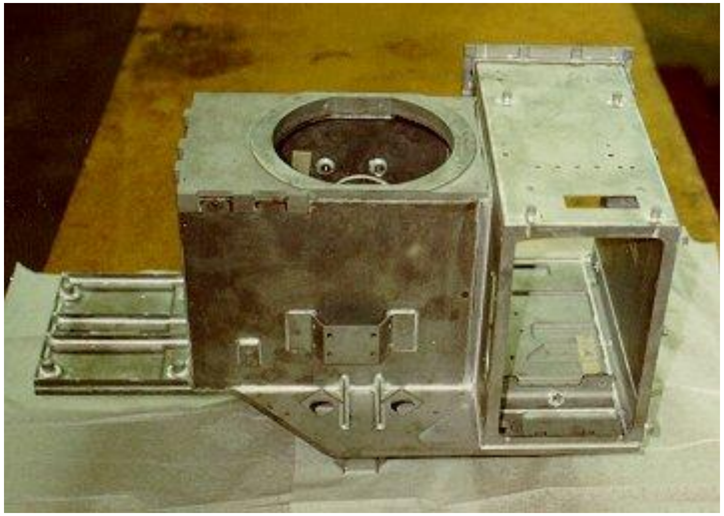
Provisions for self fixturing are also a key considerations to the success of beryllium brazing. Embedded beryllium fasteners and pins are very effective

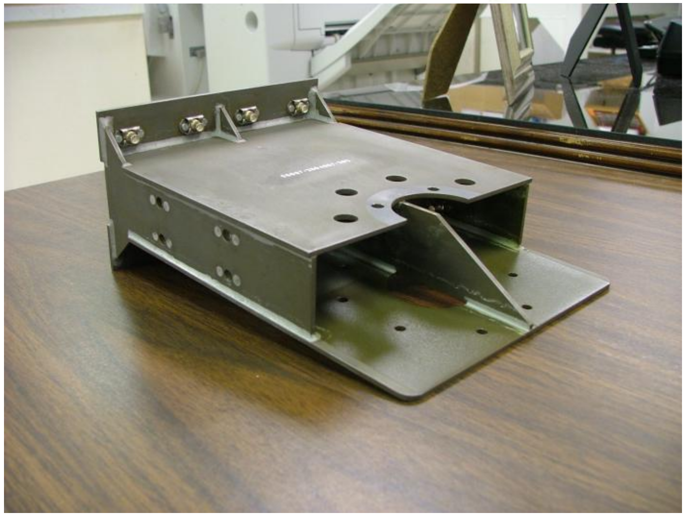
The tensile and shear strength of the braze joint: 10-12 kpsi.

Braze fill factor generally greater than 98%. Helium tight brazed beryllium heat exchangers and closed back center light weight mirrors have been successfully manufactured.

Beryllium Brazing Examples







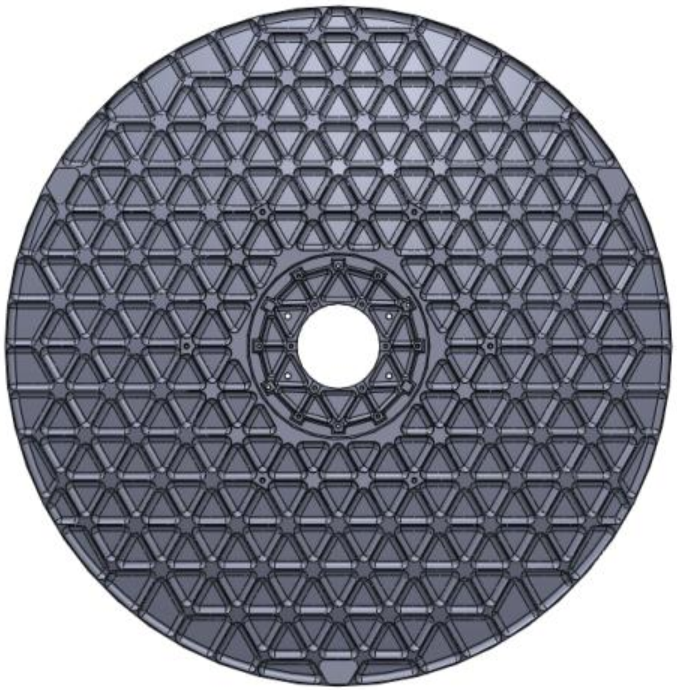
Electroless Nickel Plating

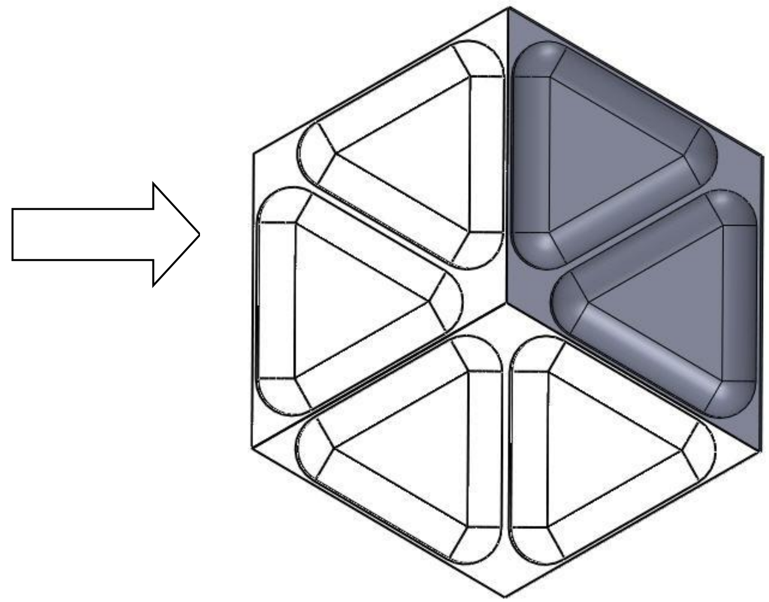
Electroless nickel plating (ENP) is critical to the manufacture of visible wavelength quality beryllium mirrors.

ENP is readily diamond point machined and post polished.

Thin and appropriately balanced ENP is critical to minimize the effects of bi-metallic bending distortion over operational temperature extremes

FEA: Beryllium Mirror Nickel Thickness





A simplified version of a typical primary mirror isogrid pocket structure having no curved surfaces was analyzed to provide a relative comparison of various nickel plating thickness combinations.

FEA: Beryllium Mirror Nickel Thickness

		Peak to Valley Deformation (µin)				
		Front Nickel (in)				
		0.000000	0.000700	0.001400	0.002100	0.003000
Back Nickel (in)	0.000000	0.00	0.93	1.85	2.76	3.94
	0.000150	0.62	0.64	1.19	2.46	3.63
	0.000700	2.89	2.29	1.69	1.55	2.65
	0.001400	5.74	3.02	4.55	3.95	3.19
	0.002100	8.56	7.97	7.37	6.77	6.01
	0.003000	12.13	11.50	10.94	10.35	9.59

FEA results on a generic light weighted beryllium mirror unit cell illustrates that the thinnest nickel practical on the mirror surface balanced by about 5X less nickel on the back structure produces the best results.

Diamond Point Turning

0.50-1.50 meter nickel plated axially symmetric beryllium primary mirrors can be diamond point turned to produce near net figure and finish prior to final polishing.

Mirrors exceeding about 0.75 meter aperture can be diamond point machined with two blended cuts.

Diamond Point Turning (GLAS M1)

Diamond Point Turning (GLAS M1)

The 1.0 meter GLAS primary mirror was successfully diamond point turned to an accuracy of less than 9 waves P-V @632.8nm.

The blended region was matched within about 1.5-2.0 waves P-V with some tilt between the inner and outer areas.

Some adjustment in base radius was introduced to correct for some change in curvature caused from the electroless nickel plating. This adjustment was well within tolerances but was necessary to maintain a thin and balanced nickel thickness condition.

The edges of the inner and outer clear apertures were well defined and the surface finish was <150 Angstroms RMS with low slopes error except in the blend region

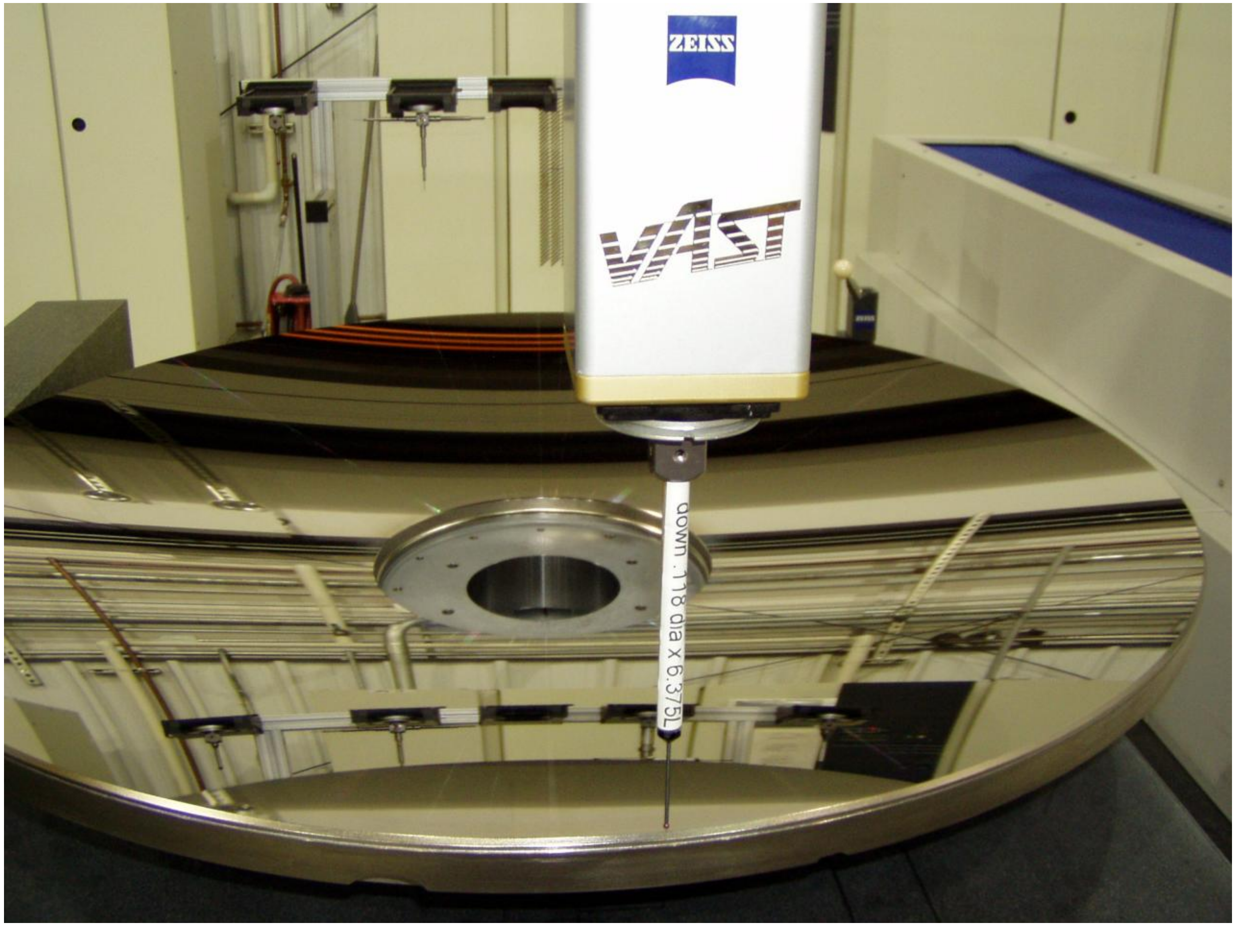
The developed process is scalable to 1.5 meter mirrors on existing equipment

Coordinate Measurement Machine (CMM)

Large, high precision coordinate measurement machines (CMM), are critical to manufacture of large beryllium mirrors and structural components.

CMM point clouds are also used to calculate best fitted error hit maps for computerized loose abrasive grinding processes prior to electroless nickel plating, diamond point machining, and final polishing

Coordinate Measurement Machine (CMM)



1.0 meter GLAS primary mirror undergoing CMM inspection for optical figure using a Zeiss CMM capable of measuring 1.5 meter optics

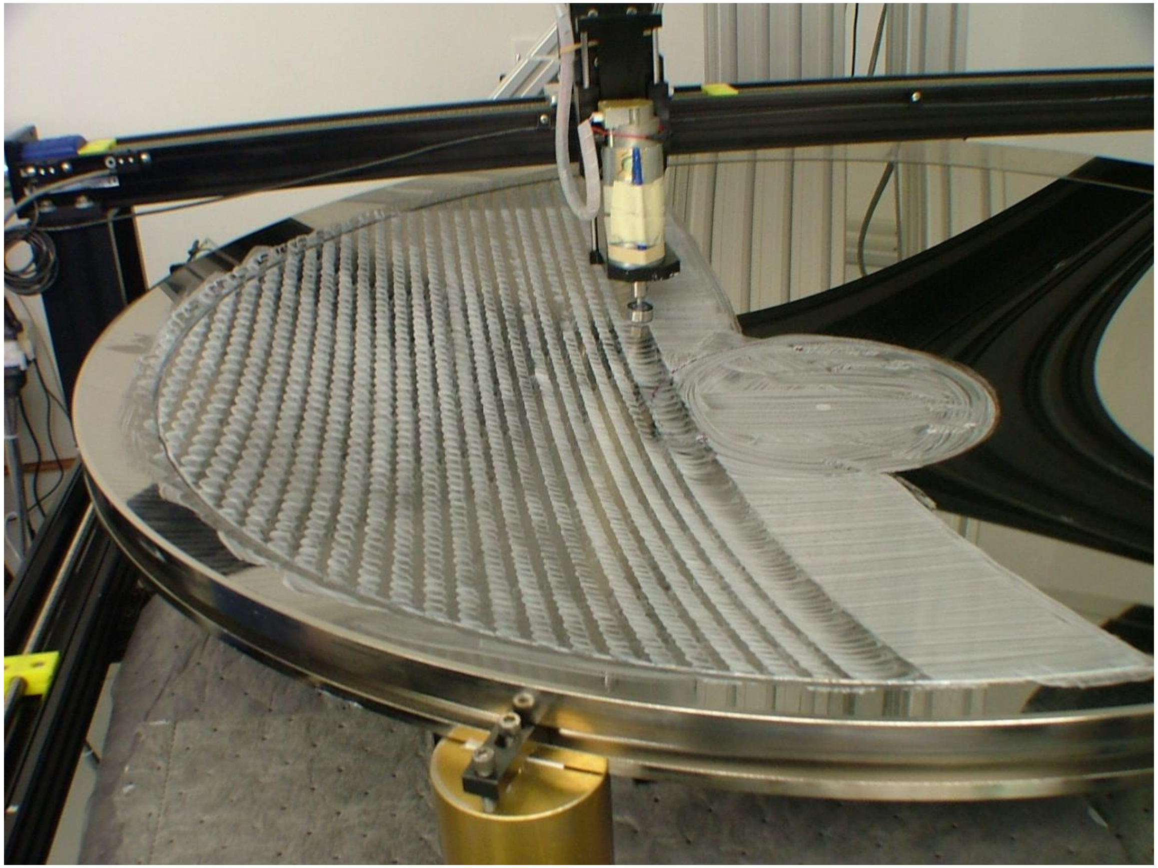
General Polishing and Null testing

FEA work on the 1.0 meter GLAS primary mirror demonstrates that 1.0 g offset is negligible if the mirror and telescope assembly is face up during interferometric measurement.

Polishing work on the both the GLAS primary and secondary mirrors was performed with in situ vertical axis interferometry scaleable to 1.5 meter aperture.

Use of CGH and diamond turning for the primary mirror allows seamless use of hyperbolic or general aspheric design form over parabolic form.

Computer Polishing (GLAS M1)



CNC loose abrasive grinding of bare beryllium and polishing of electroless nickel plating is a critical technology for large aperture mirrors. Interferometer stage is mounted above the mirror.

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Null test metrology: GLAS Primary Mirror

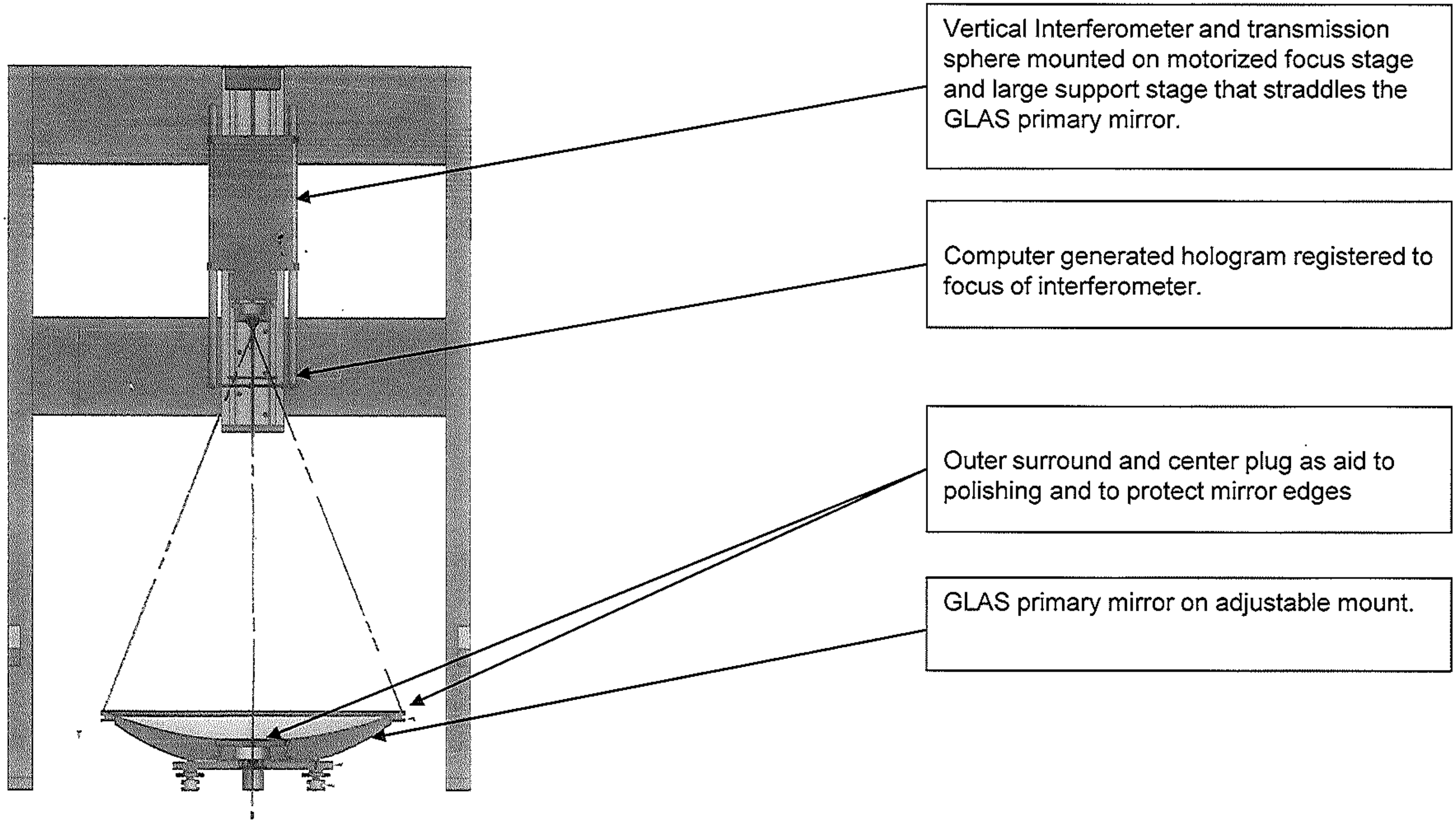
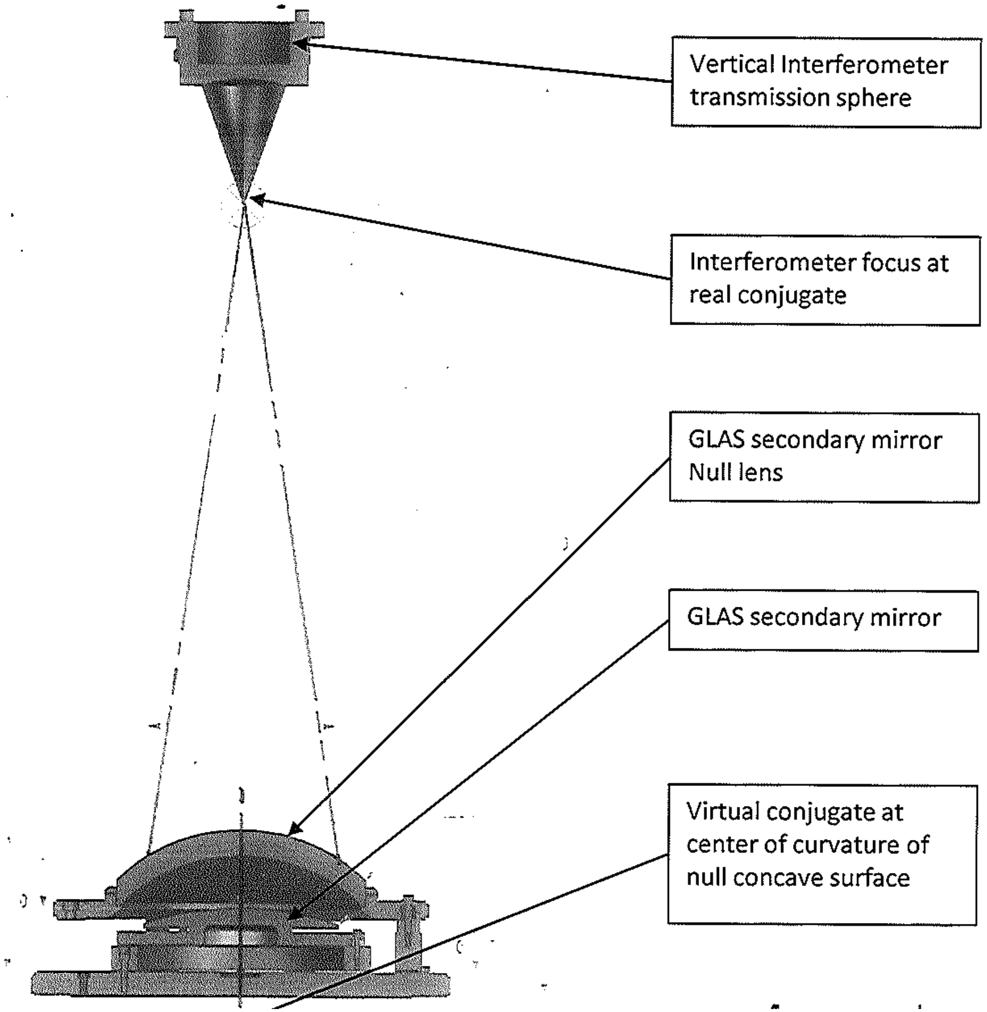
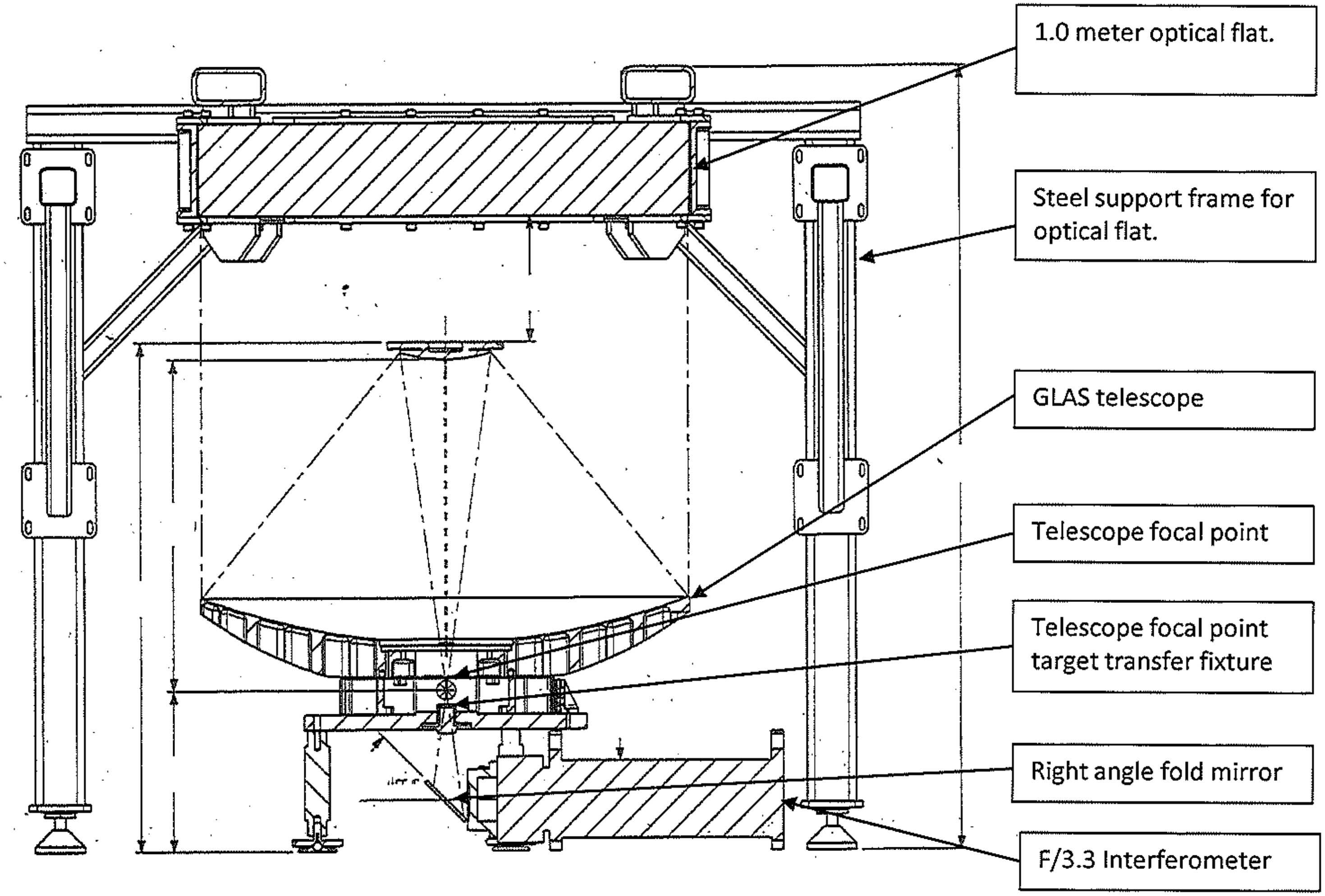


Figure 2: Diagram of the vertical axis interferometric null test for the GLAS telescope primary mirror.

Null test metrology: GLAS Secondary Mirror



System Testing (GLAS telescope)



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Optical Coating:

Once the nickel plated beryllium mirrors are completed and fully verified for dimensional stability, an optical coating is then applied along with accompanying witness samples.

The mirrors for the 1.0 meter GLAS telescope will be plated in house using electroplated gold thus saving significant cost and handling risks.

Evaporated dielectric protected coatings can also be applied.

Extreme care in cleaning, transport, and handling, of finished mirrors when applying an optical coating is imperative.

Conclusions:

0.50-1.5 meter axially symmetric beryllium telescopes are currently being manufactured or under evaluation for GLAS, CATS, ATLAS, DESDynI, and other potential programs at NASA.

Vertically integrated design, analysis, machining, nickel plating, diamond turning, mechanical and optical metrology, optical polishing, and assembly capabilities are available for efficient project execution.

Acknowledgement

Current work on the 1.0 meter GLAS telescope and 0.60 meter CATS-ISS telescope is under contract with NASA GSFC.